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CALCULATION OF NEAR-ZONE ELECTROMAGNETIC FIELDS SCATTERED BY COMPLEX SHAPE AIRBORNE OBJECTS AND ESTIMATION OF THEIR ANGULAR COORDINATES BY ONBOARD ANTENNA SYSTEMS

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The technique of calculation of near-zone electromagnetic fields scattered by complex shape airborne objects is present. It is shown that the direction line defined by a direction finder differs from true one and depends on geometry of the object, its electrical sizes and also on mutual location of the transmitting antenna, object and receiving antenna. The results of numerical calculations for the object such as "airplane" are represented. Calculation was carried out in a centimeter band, separately in a plane of course and pitches one, radiation – monochromatic. The angle of object elevation is constant and it is equal to three degrees.

Most of modern airborne objects have complex geometrical shape of its surface. The character of reflections depends from orientation of object with reference to the direction of sounding. The scattered field incident on the antenna aperture is the result of interference of waves reflected from separate units of object surface. The contribution to the resulting field of components with different amplitudes and phases results in the not plane phase front of the scattered electromagnetic wave. The distortion of phase front causes to deflection of the measured target angular position from true one as the direction line is defined as a normal to a phase front [1]. The calculation technique includes simulation of the object surface by the system of triangular facets [2]. In a Figure 1 the model of a standard airplane with a wings span of 20 meters is represented. The calculations of scattered field consist of a numerical integration of surface current densities for each facet in barycentric coordinates. The calculations were carried out by means of special cubature formulas permitting to evaluate integrals of high-oscillatory functions [2].

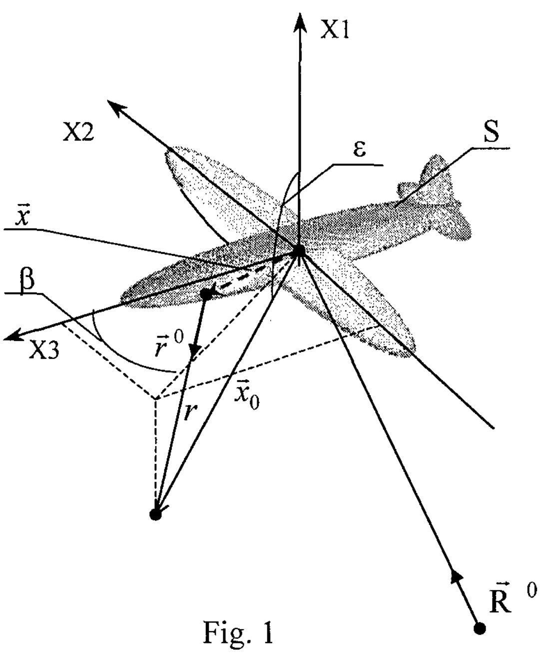

Fig. 1

The electrical dimensions of the object are large. In this case acceptable Kirchhoff approximation. Let a plane electromagnetic wave incidents on perfectly conducting scatterer with surface S located in the free space

$$\vec{E}^0(\vec{x}) = \vec{p}\exp\left(-jk\left(\vec{R}^0\vec{x}\right)\right), \quad \vec{H}^0(\vec{x}) = \left(\vec{p}\times\vec{R}^0\right)\sqrt{\frac{\varepsilon_0}{\mu_0}}\exp\left(-jk\left(\vec{R}^0\vec{x}\right)\right), \tag{1}$$

where $\vec{R}^0$ is the unit vector of sounding direction; $\vec{p}$ is the vector of polarization; k_0 is the wave number of free space; ε_0, μ_0 are permittivity and permeability of free space accordingly; $\vec{x}$ is the position vector of object surface point (Figure 1).

If $\dot{\vec{E}}(\vec{x}), \dot{\vec{H}}(\vec{x})$ are vectors of total field then scattered field will be defined by formula $\dot{\vec{E}}^s(\vec{x}) = \dot{\vec{E}}(\vec{x}) - \dot{\vec{E}}^0(\vec{x})$. Let in some point x_0 somewhere outside of S the electric dipole with the vector-moment $\vec{p}$ is located. Vector $\vec{p}$ is arbitrary on the value and direction. This dipole creates a field. Applying a Lorentz lemma, we have

$$j\omega\vec{p}\dot{\vec{E}}^S\left(\vec{x}_0\right) = \int_S \left[\dot{\vec{H}}^\perp(\vec{x})\dot{\vec{E}}_0^{eT}\left(\vec{x}/\vec{x}_0,\vec{p}\right) - \dot{\vec{E}}^T(\vec{x})\dot{\vec{H}}_0^{e\perp}\left(\vec{x}/\vec{x}_0,\vec{p}\right)\right]ds, \tag{2}$$

where

$$\dot{\vec{H}}^\perp = \vec{n}\times\dot{\vec{H}} \qquad \dot{\vec{E}}^T = \dot{\vec{E}} - \vec{n}\left(\vec{n}\dot{\vec{E}}\right) \qquad \dot{\vec{E}}_0^{eT} = \dot{\vec{E}}_0 - \vec{n}\left(\vec{n}\dot{\vec{E}}\right) \qquad \dot{\vec{H}}_0^{e\perp} = \vec{n}\times\dot{\vec{H}}_0 \quad - \tag{3}$$

the tangential components of electrical and magnetic fields. $\vec{n}$ – is the unit normal vector to the object surface. For the perfectly conducting scatterer $\dot{\vec{E}}^T|_S = 0$ and consequently the integrand function is zero.

The field of an electric dipole can be represented in the form

$$\dot{\vec{E}}_0^{eT}(\vec{x}/\vec{x}_0,\vec{p}) = \frac{1}{\varepsilon_0}\left[\vec{\nabla}\left(\vec{p}\vec{\nabla}\right)\dot{G} + k_0^2\vec{p}\dot{G}\right], \tag{4}$$

where $\dot{G} = e^{jk_0 r}/4\pi r$; $\vec{r}^0 = \left(\vec{x}_0 - \vec{x}\right)/r$; $r = |\vec{x}_0 - \vec{x}|$ – the distance between object and receiving antenna; $\vec{p} = \vec{p}^{\parallel} + \vec{p}^{\perp}$ are longitudinal and tangential component of polarization vector. Taking into account that in Kirchhoff approximation formula (2) for a scattered field

$$\vec{p}\dot{\vec{E}}^s\left(\vec{x}_0\right) = \frac{1}{2\pi jk_0}\oint_{S_s}\frac{1}{r}\left[\vec{R}^0(\vec{p}\vec{n}) - \vec{p}\left(\vec{R}^0\vec{n}\right)\right]\left[\left(k_0^2 + \frac{jk_0 r - 1}{r^2}\right)\vec{p}^\perp - \right.$$
$$\left. - \frac{2\left(jk_0 r - 1\right)}{r^2}\vec{p}^{\parallel}\right]e^{jk_0\left(r + \left(\vec{R}^0\vec{x}\right)\right)}ds_s, \tag{5}$$

where S_S is "illuminated" part of object surface. Using the representation (5) calculations of scattered field were carry out for $\beta = 0 \ldots 90^0$ and $\varepsilon = 75^0, 85^0, 95^0$. For example, in Fig. 2 results of calculation for $\varepsilon = 75^0$ and $r = 200\mathrm{m}$ are presented. Direction finding accuracy depends on the type of angle discriminator and amplitude-phase distribution (APD) in antenna aperture. In this paper we simulated combined calculation accuracy is given by the antenna: in β-plane – amplitude method of

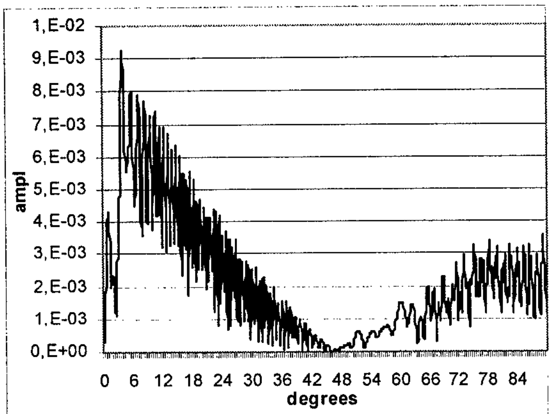

Fig. 2

direction finding; in ε-plane – phase one. Such finding direction functioning is described by expression

$$U_{1,2}(\vec{x}_0) = \oint_{S_{ap}} \vec{E}^s(\vec{x}_0)\vec{A}_{1,2}(\vec{x}_0)dS_{ap},$$

where $\vec{A}_{1,2}(\vec{x}_0)$ is APD in antenna aperture for two channels of receiving antenna, S_{ap} is aperture area. Deviation of measured object bearing from true one is determined by expressions $r(c) = \mathrm{Re}[U_s U_d^*]/U_s U_s^*$ – for course-plane and $r(p) = \mathrm{Re}[U_s U_d^* \exp(j\pi/2)]/U_s U_s^*$ – for pitch-plane, where $U_s = U_1 + U_2$, $U_d = U_1 - U_2$. For example dependences of $r(c)$ and $r(p)$ from angle β are shown in Figures 3, 4.

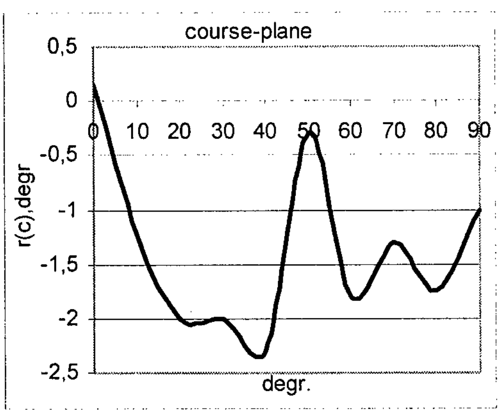

Fig. 3

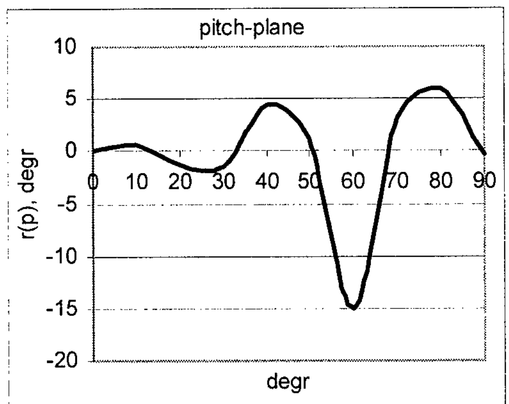

Fig. 4

The analysis of Figures 3, 4 have shown that in the course-plane the deviation can be obtained the values 1,7-2,3 degrees. In the pitch-plane it possible to obtain 15 degrees. For azimuth 60^0 in the ε-plane the angular deviation is more than object angular size.

By using proposed technique one can efficiently calculate the errors in airborne object direction finding appearing in short-range radar.

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